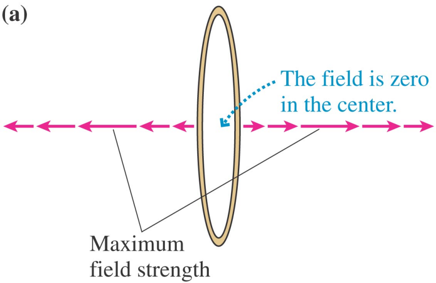
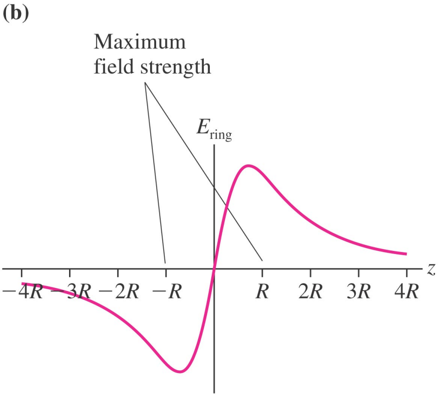
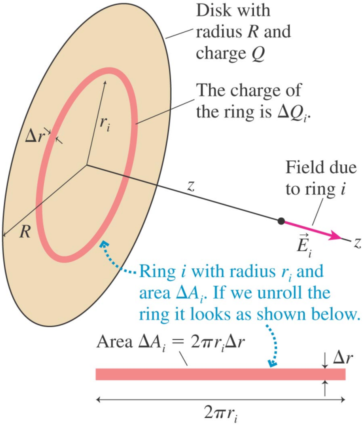
Electric Field from A Thin Ring





A Disk of Charge



- Now we will move from lines to surfaces. First, let's try a disk of zero thickness and charge density

$$\eta = \frac{Q}{A} = \frac{Q}{\pi R^2}$$

Again, we will look at an on-axis point.

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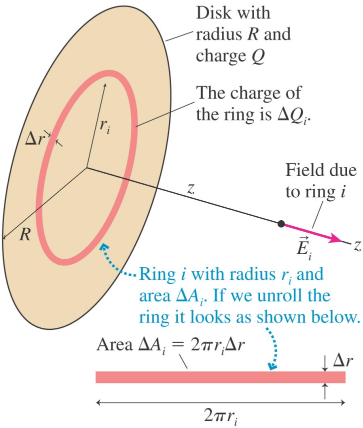

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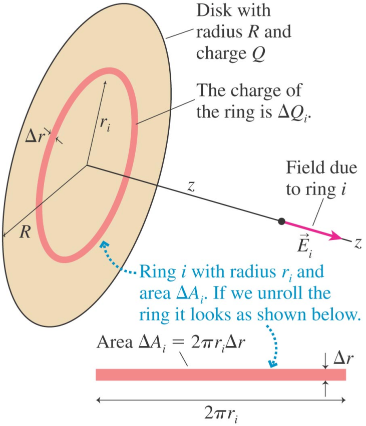
$$\eta = \frac{Q}{A} = \frac{Q}{\pi R^2}$$

Again, we will look at an on-axis point.

- Now we know how to deal with a thin ring. So, we'll take a bunch of thin rings together and make then into a disk! Each ring gives

$$E_z = \frac{1}{4\pi\epsilon_0} \frac{z \Delta Q_i}{(z^2 + r_i^2)^{3/2}}$$

A Disk of Charge



- So, now we need to sum over many rings

$$E_z = \frac{z}{4\pi\epsilon_0}\sum_{i=1}^{N}\frac{\Delta Q_i}{(z^2 + r_i^2)^{3/2}}$$

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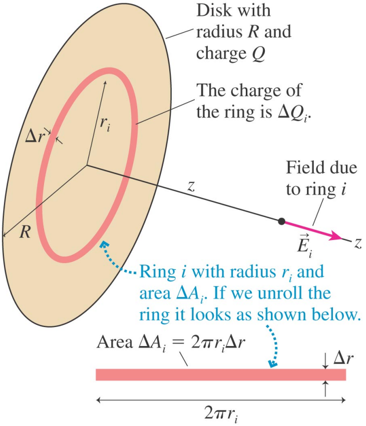

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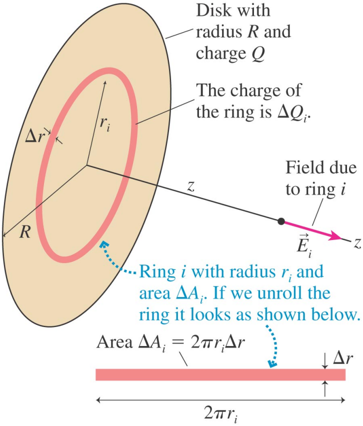

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- Let's use the area of a ring and the surface charge density. The area of a ring is

$$\Delta A_i = 2\pi r_i \Delta r$$

and the charge is

$$\Delta Q_i = 2\pi\eta r_i \Delta r$$

A Disk of Charge

- Writing out the sum

$$E_z = \frac{\eta z}{2\epsilon_0} \sum_{i=1}^{N} \frac{r_i \Delta r}{(z^2 + r_i^2)^{3/2}}$$

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$$\begin{aligned} u &= z^2 + r^2 \\ du &= 2 r dr \\ r dr &= \frac{1}{2} du \end{aligned}$$

- And the limits of integration change too...

A Disk of Charge

- The integral becomes

$$E_z = \frac{\eta z}{2\epsilon_0}\frac{1}{2}\int_{z^2}^{z^2+R^2}\frac{du}{u^{3/2}}$$

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E_z &= \frac{\eta}{2\epsilon_0}\left[1-\frac{z}{\sqrt{z^2+R^2}}\right]
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$$(1+x)^n \simeq 1 + nx, x \ll 1$$

So

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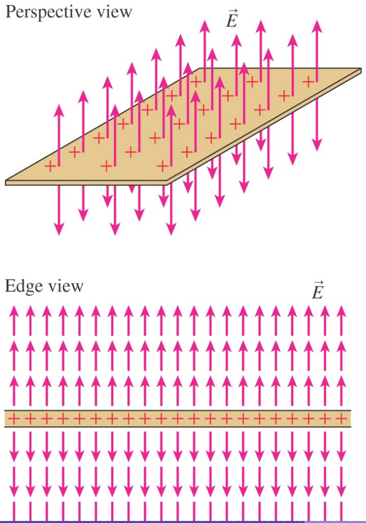
- Substituting this approximation into our field equation gives

$$E_z = \frac{1}{4\pi\epsilon_0}\frac{Q}{z^2}$$

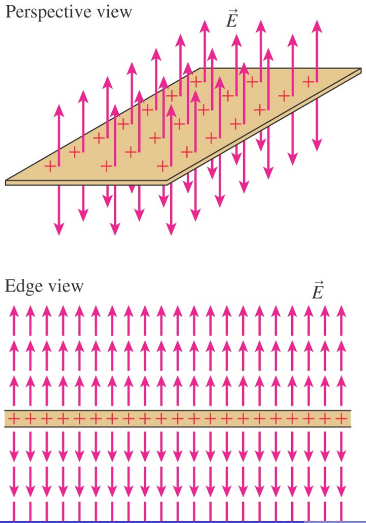
Hurray!!

A Plane of Charge



- We model important electronic components (eg. electrodes) as planes of charge.

A Plane of Charge



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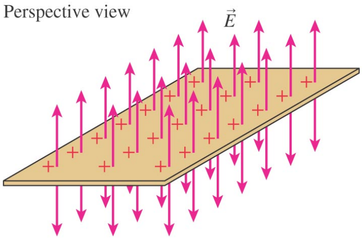

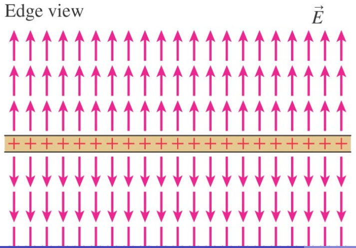

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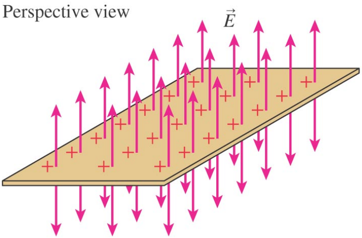

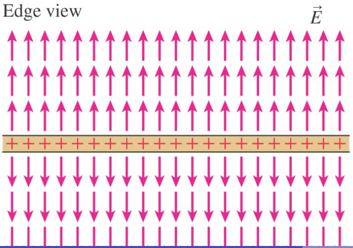

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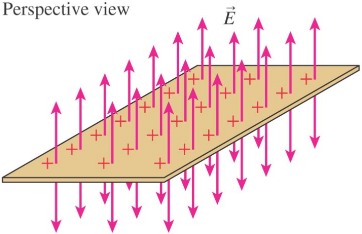

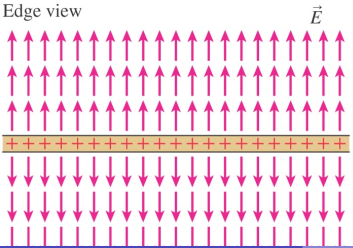

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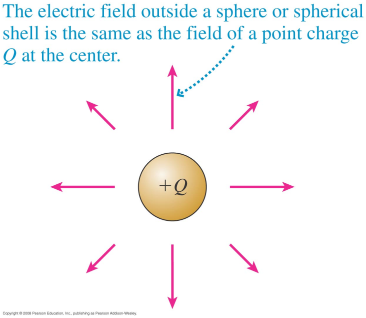

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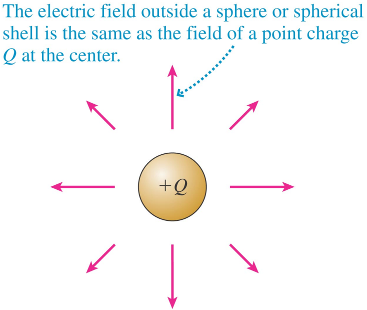

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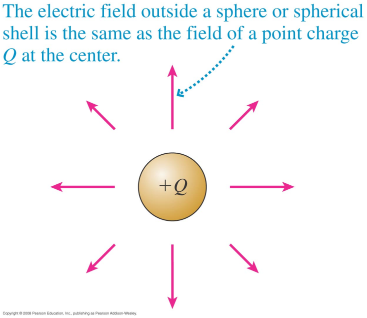

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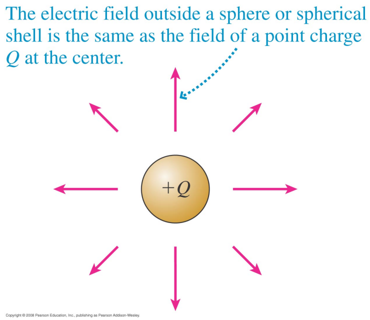

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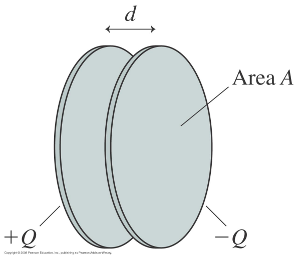
- What is the field inside?

A Parallel Plate Capacitor (27.5)



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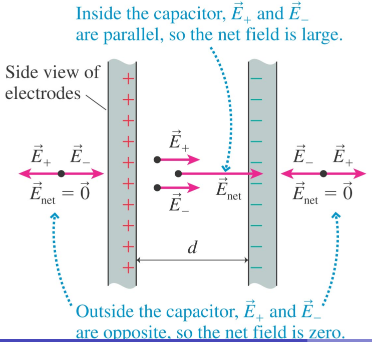
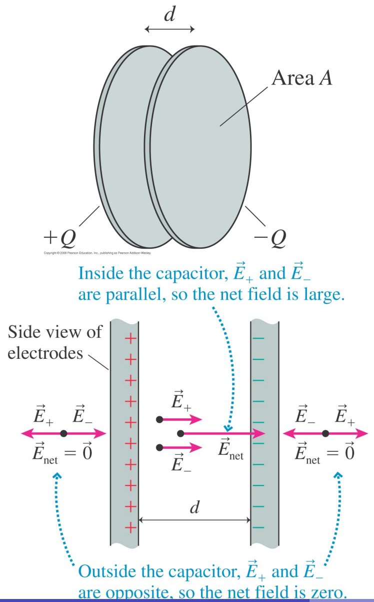


- A parallel plate capacitor is formed from two large area plates (relative to their separation) of equal and opposite charge ($+Q$ and $-Q$).

A Parallel Plate Capacitor (27.5)



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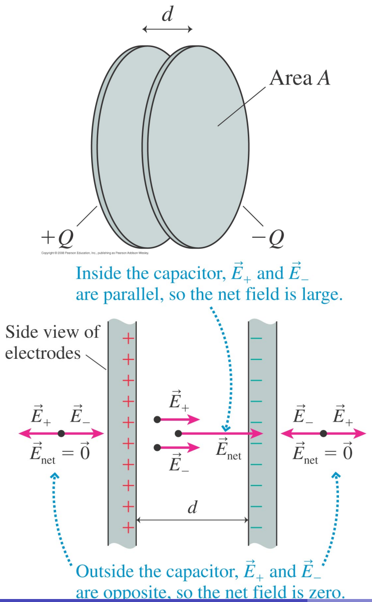

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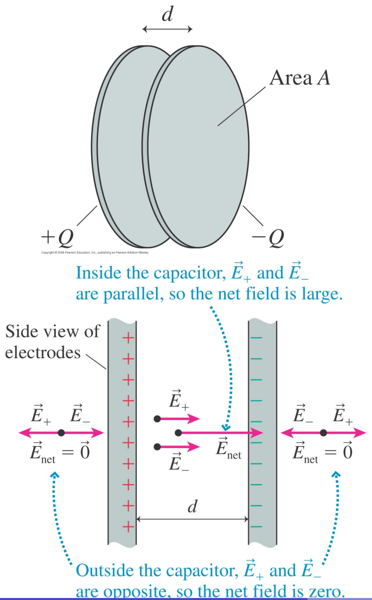

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- Note that its net charge is zero but some charge has been transferred from one plate to the other.
- Opposite charges atract, so the extra charge sits on the inner surface of each plate.

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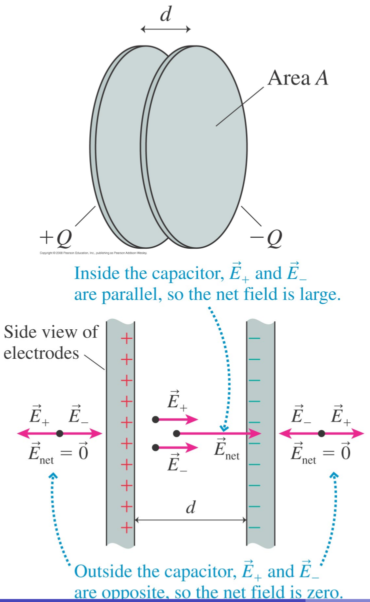

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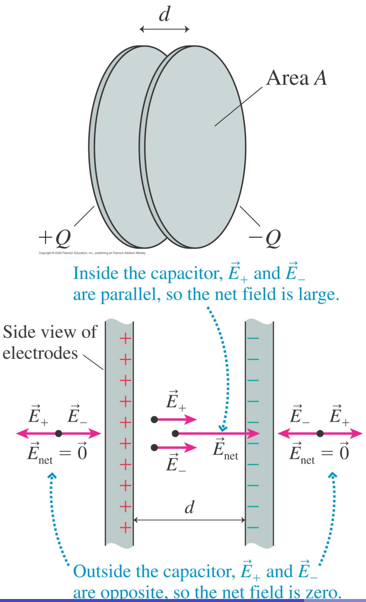

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- The net electric field inside the capacitor is then

$$\vec{E}_{capacitor} = \vec{E}_+ + \vec{E}_- = \frac{\eta}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$$

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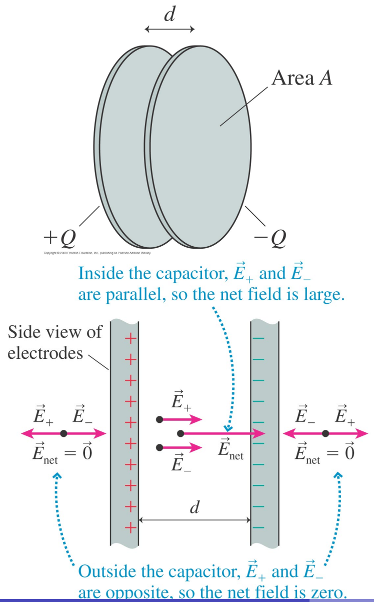

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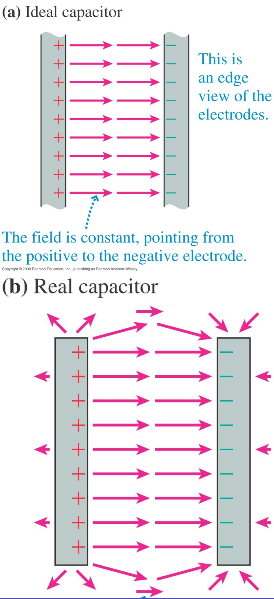
- Outside the capacitor a test charge would see an opposite field from the positive and negative plate. Since the plates are “infinite” the fields would be identical strength...there is no field!!

A Parallel Plate Capacitor



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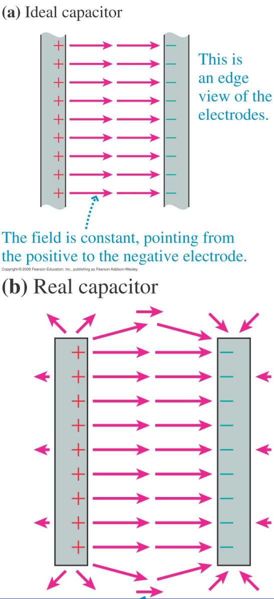

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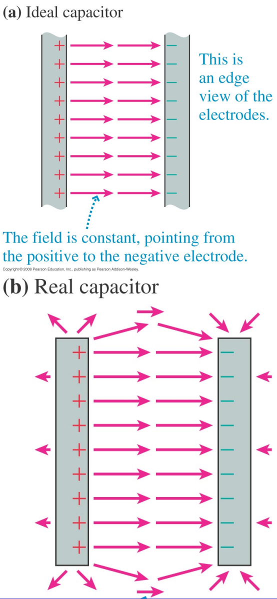

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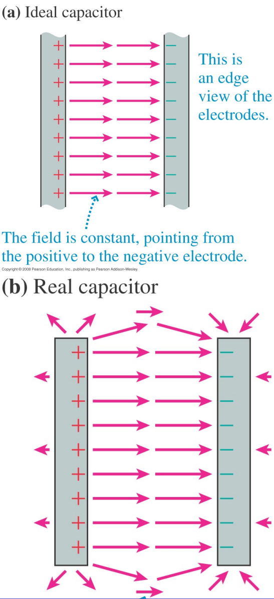

- An ideal capacitor has a strong electric field between the plates
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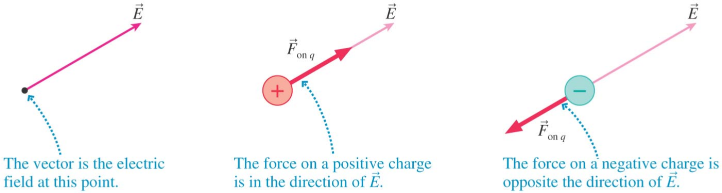
- A real-world capacitor has a fringe field outside the capacitor.
- Capacitors create a uniform electric field which is highly useful in manipulating a charged particles.

Motion of a Charged Particle in an Electric Field (27.6)



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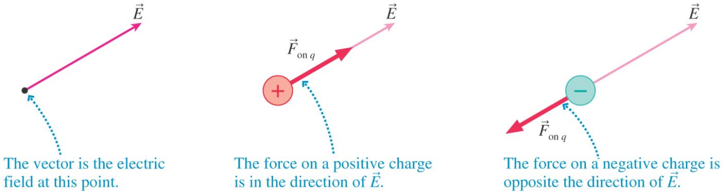

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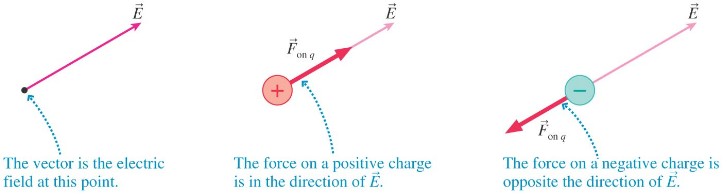

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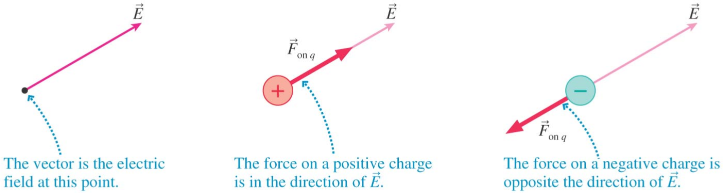

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- q/m is called the charge-to-mass ratio. Two equal charges with different mass experience the same force but different acceleration

Motion of a Charged Particle in a Uniform Field

- Using a capacitor to generate a uniform field has many important applications. A charged particle will move with constant acceleration in a uniform field:

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- We can use a parallel plate capacitor to make a beam of electrons and accelerate the particles.
- We could then use another capacitor to steer the beam.

Example 27.8 - an Electron Moving Across a Capacitor

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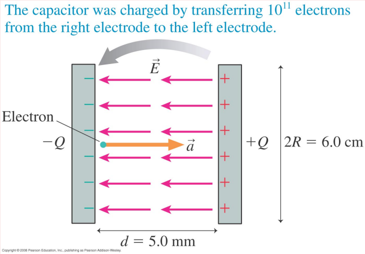

Two 6.0-cm-diameter electrodes are spaced 5.0 mm apart. They are charged by transferring 1.0×10^{11} electrons from one electrode (plate) to the other.

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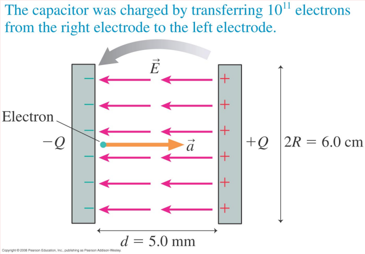

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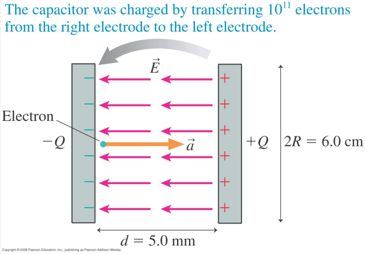

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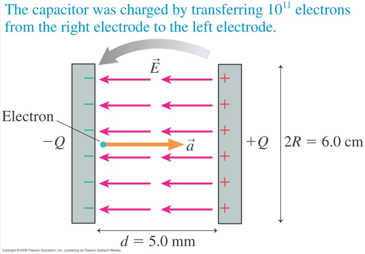

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$$\begin{aligned} x_f = d &= \frac{1}{2} a (\Delta t)^2 \\ \Delta t &= \sqrt{\frac{2d}{a}} = 3.0 \times 10^{-10} \text{ s} = 0.30 \text{ ns} \end{aligned}$$

- The speed of the electron when it reaches the positive plate is

$$v = a\Delta t = 3.3 \times 10^7 \text{ m/s}$$

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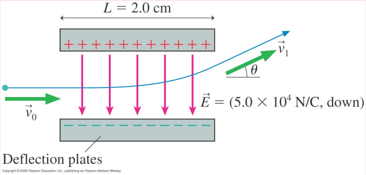

An electron gun creates a beam of electrons moving horizontally with speed 3.3×10^7 m/s. The electrons enter a 2.0-cm-long gap between two parallel electrodes where the electric field is $\vec{E} = (5.0 \times 10^4 \text{ N/C}, \text{down})$.

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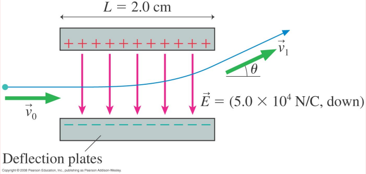

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Example 27.9 - Deflecting an Electron Beam

- The electron enters with velocity $\vec{v}_0 = 3.3 \times 10^7 \hat{\imath}$ m/s and exits with $\vec{v}_1 = v_{1x}\hat{\imath} + v_{1y}\hat{\jmath}$.

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- There is no horizontal force, so the x-component of velocity does not change. The time to cross the plates is then known:

$$\Delta t = \frac{L}{v_{0x}} = \frac{0.020m}{3.3 \times 10^7 \text{ m/s}} = 6.06 \times 10^{-10} \text{ s}$$

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- However, there is an upward acceleration of magnitude

$$a = \frac{eE}{m} = \frac{(1.60 \times 10^{-19} C)(5.0 \times 10^4 \text{ N/C}}{9.11 \times 10^{-31} \text{ kg}} = 8.78 \times 10^{15} \text{ m/s}^2$$

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- Giving a final vertical velocity of

$$v_{1y} = v_{0y} + a\Delta t = 5.3 \times 10^6 \text{ m/s}$$

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- So, the final velocity is

$$\vec{v} = (3.3 \times 10^7 \hat{\imath} + 5.3 \times 10^6 \hat{\jmath})\ \text{m/s}$$

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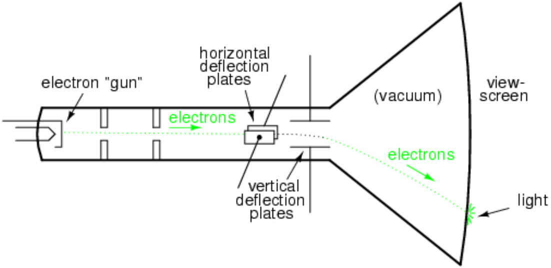
- We use the same mathematics as for mechanics/gravity...but the magnitudes of acceleration, velocity, etc. are much higher than what we are used to!
- In case you wondered why you bothered to do some special relativity last term...consider the speeds of these electrons!

Examples: Your Oscilloscope is a CRT



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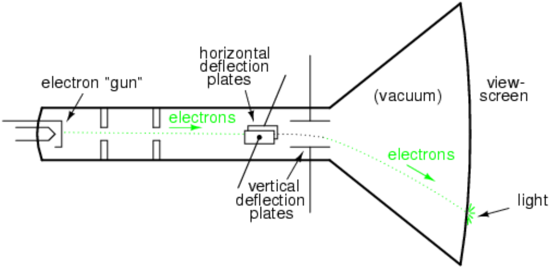
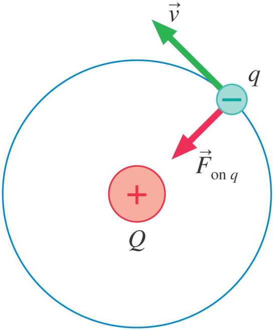


- Some oscilloscopes use an electron gun with vertical and horizontal deflection plates to control the beam.
- The electron diffraction apparatus demonstrated in class used parallel charged plates to control the electron beam's direction.

Motion in a Non-Uniform Field



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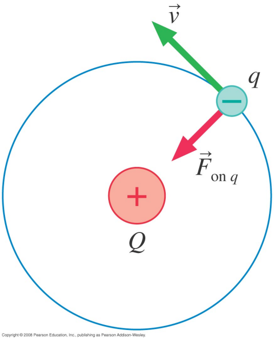

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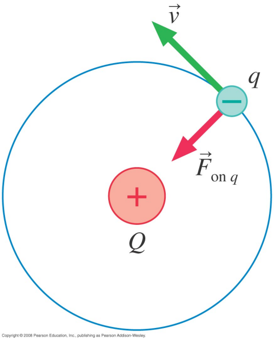

- A non-uniform field is much more difficult to deal with.
- However, one simple example is a negatively charged particle orbiting a positively charged one.
- Same mathematics as the moon orbiting the earth. The charge can move in a circular orbit if

$$|q|E = \frac{mv^2}{r}$$